Microelectronics Technology Breakout: All Requirements Have Equal and High Priority

1. Board-Level Effects in Space
2. Dose-Rate Temporal Effects in Circuit and Device Response to Enhanced Low Dose Radiation Susceptibility
3. Validation of Models for Heavy Ion-Induced Latent Damage Reduction in Residual Oxide Lifetime Under Voltage Stress in Ultra-thin Oxides
4. Flight Evaluation of Hardened-By-Design (HBD) Techniques for Microelectronics
5. On-Orbit Assessment of Single Event Effects in Ultra-High Speed Technologies
6. Combined Space Radiation Effects on Micro-Electro-Mechanical Systems (MEMS) and Accompanying Microelectronics Devices and Circuits
7. Current and Emerging Non-Volatile Memory (NVM) Technologies in the Space Environment
8. Optical and Radiofrequency Circuit Response to the Mixed Space Radiation Environment
9. Effects of Combined Space Radiation Environment on Power Electronics
10. Reconfigurable, Environmentally Aware and Adaptable Computing Technology
11. Space Validation and Verification of Advanced 3-Dimensional Single Event Upset Models for High-Density Commercial Memories
12. Response of Advanced, Mixed-Signal Commercial-Off-the-Shelf Devices to the Space Radiation Environment

Technology #1: Board-Level Effects in Space

- **Background: Significant reductions in cost and schedule could be realized if microelectronics qualification could be done at the board level instead of at the individual component level.**
  - However, qualification at the board level has not been flight validated.
  - Successful validation will permit the separation of effects from each component of the mixed environment in space.
- **Technology Requirement: Perform flight experiments to demonstrate board-level vulnerabilities and board-level radiation (single event upset or total integrated dose) mitigation strategies.**
  - Compare data from space with data from ground tests to validate the ground test protocol.
- **Correlative environment measurement requirements:**
  - TID, protons, heavy ions
- **Environments of interest: GEO, GTO, Polar if LEO used; altitude > 2000 km**

Technology #2: Dose-Rate Temporal Effects in Circuit and Device Response to Enhanced Low Dose Radiation Susceptibility (ELDRS)

- **Background: Previous space experiments looking at ELDRS did not have the time resolution to examine temporal effects such as dose rate changes during solar events.**
  - The physics of ELDRS is not entirely known, including the impact and net effect of varying dose rate between very low rates where ELDRS is highly effective and moderate-to-high dose rates where other phenomena come into play.
    - **Exposure of ELDRS-sensitive parts to the highly variable dose rates characteristic of space will help to provide hardness assurance in the space environment.**
- **Issue: Frequent measurements of device responses to changes in the space radiation environment as a function of time are needed to permit correlation of the changes in responses (I.e., changes in degradation) with changes in dose rate.**
- **Correlative environment measurement requirements:**
  - Total dose and dose rate as a function of time, with enough granularity to measure variations in dose rate
- **Environments of interest: HEO and GTO environments**

Technology #3: Validation of Models for Heavy Ion-Induced Latent Damage Reduction in Residual Oxide Lifetime Under Voltage Stress in Ultra-thin Oxides

- **Background: Gate oxides are common to all advanced CMOS processes.**
  - Recent testing showed that fluences as low as 10^5 ions/cm^2 significantly degrade the residual oxide lifetime under voltage stress, threatening circuit performance.
  - Accurate modeling is difficult, because a many variables affect breakdown.
    - **The very high energy, heavy ions in space cause this latent damage; ground testing cannot produce these energies.**
- **Issue: Data from space is needed to quantify residual oxide lifetime under voltage stress, a statistical quantity, and to separate this effect from other effects that also produce breakdown.**
  - Cells that will provide monitoring to predict long-term reliability in a space environment can be developed for a particular technology, but they require calibration in a space environment.
- **Correlative environment measurement requirements:**
  - Heavy ions and total integrated dose
- **Environments of interest: Any environment with significant heavy ion exposure such as GTO or GEO**

Technology #4: Flight Evaluation of Hardened-By-Design (HBD) Techniques for Microelectronics

- **Background: Hardening by design, an emerging area, decreases vulnerability to space radiation effects by taking advantage of commercial microelectronics processes for higher performance and lower power.**
  - Flight evaluation of HBD techniques will validate designs that are simultaneously exposed to total dose effects, displacement damage and single event effects, a combined environment that cannot be duplicated on the ground.
- **Issue: Simultaneous characterization of the performance of several device-level design hardening strategies to mitigate radiation effects and non-hardened components in space is needed.**
  - Compare data from space with ground test data.
- **Correlative environment measurement requirements: total integrated dose, protons, and heavy ions**
- **Environments of interest: High LEO, MEO, GTO environments**
  - Total dose should be commensurate with expectations for HBD designs environments

Technology #5: On-Orbit Assessment of Single Event Effects in Ultra-High Speed Technologies

- **Background: High-speed technologies show great promise for space applications, because they have improved noise and power performance.**
  – However, data from space show that existing models for predicting single event upset rates may not be applicable.
  – Models being developed for high speed technologies require validation using data from space.
- **Issue: Characterize the performance of high-speed microelectronics in the space environment.**
  – Use the data to validate ground test protocols and rate prediction models. Technologies of interests include SiGe, SOI, SOS, InP.
- **Correlative environment measurement requirements:**
  – Proton and heavy ion flux
- **Environments of interest: GTO and HEO environments are preferred over a high inclination LEO environment**

Technology #6: Combined Space Radiation Effects on Micro-Electro-Mechanical Systems (MEMS) & Accompanying Microelectronics Devices & Circuits

- **Background: MEMS have been shown to be sensitive to electrostatic charging effects due to electron and proton irradiation, but MEMS response in space is not known.**
  - For example, the output voltage of accelerometers has been shown to shift in opposite directions when irradiated by electrons and protons.
- **Issue: Characterize the output response of MEMS devices during electron and proton space irradiation.**
  - Ground test protocols that are based upon physics and validated with space data are needed to predict MEMS response in space. The circuitry associated with MEMS complicates hardness assurance testing, and often turns out to be more sensitive than the MEMS device.
  - Compare data to ground-level electron and proton irradiation results and use it to validate test protocols based on physics-based models.
    - **Consideration should be given to unique aspects of flight qualification of MEMS (mechanical effects) and the remote measurement in space of these effects.**
- **Correlative environment measurement requirements:**
  - Total integrated dose; heavy ions (for electronics)
- **Environments of interest: GEO, GTO, and high-inclination LEO**

Technology #7: Current and Emerging Non-Volatile Memory (NVM) Technologies in the Space Environment

- **Background: Commercial non-volatile memories are dense but not tolerant to radiation. Hardened non-volatile memories are not dense.**
  - Emerging technologies (MRAM, FERAM, C-RAM) could bridge this gap and reach the goal of high density, hardened permanent memory.
- **Issue: The sensitivity of emerging NVM to the mixed radiation space environment is essentially unknown, and may involve complications not revealed by ground testing.**
  - A space experiment is needed to quantify the performance of one or more non-volatile memories (excluding battery-backed SRAM) and to correlate it with environmental data.
  - The data together with ground test data are needed to validate performance predictions and test protocols.
- **Correlative environment measurement requirements:**
  - Entire radiation field (total dose and single event upsets)
- **Environments of interest:**
  - GTO, HEO, GEO environments; altitude > 2000 km

Technology #8: Optical and Radiofrequency Circuit Response to the Mixed Space Radiation Environment

- **Background: Recent studies have demonstrated the susceptibility of radiofrequency and optical devices and circuits to radiation-induced displacement damage, total ionizing dose, and single event effects.**
- **Issue: Characterization of the responses of these communication system components to the combined, simultaneous impact of all environments is necessary for the validation of predictive models.**
  - Data from flight experiments are needed to characterize the combined radiation response of high frequency optical and/or communication subsystems at the board level.
  - Space-based testing of multiple test subsystems will enable the identification of “weak links” at the transmission and/or reception end of the communication system.
  - Some testing of subsystem components is also needed.
- **Correlative environment measurement requirements:**
  - Ionizing dose, protons
- **Environments of interest: GTO, MEO, GEO, LEO polar environments**

Technology #9: Effects of Combined Space Radiation Environment on Power Electronics

- **Background: Power electronic components and board-level products such as DC-to-DC converters are often susceptible to radiation effects.**
  - – They frequently use radiation-soft or -tolerant components and are implemented in architectures that emphasize efficiency and reduced size at the expense of hardness.
- **Issue: DC-to-DC converters contain a variety of devices, including optoelectronics, and often exhibit unexpected responses to radiation. The unexpected responses are attributed to a lack of flight validation of ground test and qualification protocols.**
    - **The power devices have very thick active regions that are difficult to penetrate with heavy ions available at accelerators; hence space test data are required.**
  - – Characterize the performance of power components or systems to one or more space radiation effects in space. Use the data to validate a ground test protocol.
- **Correlative environment measurement requirements:**
  - – Total integrated dose, protons, heavy ions
- **Environments of interest: GEO and GTO environments**

Technology #10: Reconfigurable, Environmentally Aware & Adaptable Computing Technology

- **Background: Field programmable gate array (FPGA)-based computing systems are being developed that autonomously adapt their performance to the combined radiation environment, seamlessly providing the best balance of reliability and performance.**
  - When the environment is severe, the system autonomously adapts to provide error checking and redundancy to guarantee reliable operation and re-adapts when the environment becomes benign.
- **Issue: Characterization of the performance of a reconfigurable or adaptable system in the mixed space radiation environment is required to determine the degradation of this technology and its ability to adapt to the environment.**
  - The characterization needs to include collection of data on computational throughput, average error rates, and overall performance and reliability of all system modes, comparing radiaiton-tolerant and commercial off-the-shelf FPGA implementations.
- **Correlative environment measurement requirements:**
  - Total integrated dose and protons/heavy ions
- **Environments of interest: GTO or LEO through the South Atlantic Anomaly; polar inclination if LEO environment is used**

Technology #11: Space Validation and Verification of Advanced 3-Dimensional Single Event Upset (SEU) Models for High-Density Commercial Memories

- **Background: High-density commercial memories poses significant challenges for radiation hardness assurance due to part-to-part and lot-to-lot variability and many radiation-induced error and failure modes.**
  - Because of their small feature size, advanced memories require 3-dimensional models to accurately predict their SEU rates.
- **Issue: Characterization of the performance of high-density commercial memories in an omni-directional, variable-energy heavy ion flux is required to validate the 3-dimensional SEU models and improve their hardness assurance in space use.**
  - Validation could increase the reliability for using these memories in new spacecraft and assist in anomaly resolution should anomalies occur in operational spacecraft
  - The environment cannot be produced in ground test facilities.
  - Benefiting Missions: Missions such as JWST, SDO, and GPM that require large amounts of memory to accommodate high rates of science data.
- **Correlative environment measurement requirements:**
  - Heavy ions and protons
- **Environments of interest: HEO, Interplanetary/Near Earth, MEO, Polar LEO, and GEO environments**

Technology #12: Response of Advanced, Mixed-Signal Commercial-Off-the-Shelf Devices to the Space Radiation Environment

- **Background: High performance mixed-signal microcircuits are important to missions that have high data rates. However, they are sensitive to many radiation effects including total dose, enhanced low dose radiation effects, single event effects, and displacement damage.**
  - The effect that dominates depends on the circuit design, fabrication process, required performance, and the type of radiation.
  - The contribution of each effect to the overall performance has not been characterized.
- **Issue: Characterization of the performance of mixed signal microcircuits in the combined radiation environment in space is needed to establish hardness assurance and to separate the source and contribution of each effect to the overall performance of the mixed signal device.**
- **Correlative environment measurement requirements:**
  - Ionizing dose, heavy ions, protons
- **Environments of interest: GTO with near-polar inclination**